Growth and physiological responses of ornamental plants to salinity

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Abstract

Water shortage and poor water quality are global issues. With rapid population growth and the diminishing water supply in urban areas, use of alternative water sources such as municipal recycled water and other sources of non potable waters for agriculture and landscape irrigation is inevitable. A potential concern is the elevated salt levels in these alternative waters. This paper briefly summarizes our research results on salt tolerance of a large number of ornamental plants ranging from bedding plants, herbaceous perennial and groundcovers and woody shrubs and trees. The methodology of screening and evaluating salt tolerance of ornamental plants is discussed. Like agricultural crops, a wide range of salt tolerance among ornamental plants has been found. In addition to plant species, dominant salt type, substrate, irrigation method and management, and environmental conditions also affect plant responses to salinity stress. A number of mechanisms of salinity tolerance have been observed among these ornamental species, including restriction of ion uptake, selective ion uptake, and tolerance to high internal concentrations of sodium and/or chloride.

Introduction

Ornamental crops are traditionally irrigated with high-quality water due to their high cash values and most of them were considered sensitive to salinity. With the increasing population and industrial development, high quality fresh water is becoming a limited and expensive resource in many regions of the world. Agriculture, including ornamental industry, has to compete with industrial and domestic water uses. It is time to explore alternative water sources such as municipal recycled water and brackish groundwater for agricultural irrigation. The municipal recycled water (also called "reclaimed water") is the only water source that increases with population growth (Qian et al, 2005). In the U.S. (Dobrowolski et al., 2008; Morgan et al., 2008) and other countries (Pasternak and Malach, 1994; Safi et al., 2007; Tanwar, 2003), the municipal recycled water has already been used for irrigating urban landscapes and field crops for decades where potable water supply is limited. The potential problem for using these alternative water sources is the high salt levels, which causes salt damage or even death on sensitive plants, if not managed properly.

Soil salinity is already a problem in arid and semi-arid areas where irrigation is practiced. Over 50% of all irrigated lands are affected by salinization, yet the water used for irrigating these lands was seldom saline (Pasternak and Malach, 1994). Soil salinization would become even worse with more and more alternative or low quality water is being or will be used for irrigation. In addition, continuous sea-level rise in a warming world threatens increased salinity in coastal lowlands (Rozema and Flowers, 2008). As fertile soils become salinized, the yield of conventional crops decreases (Pasternak and Malach, 1994).

One of the common solutions to overcome salinity problems is the introduction of salt tolerant crops. Like agronomic crops, salt tolerance of ornamental plants varies largely with species and even cultivars within a species. Therefore, screening and

evaluating the salt tolerance of commercially important ornamental plants are imperative. Such evaluations may facilitate improvement of salt tolerance of ornamental plants in breeding and bioengineering programs or prove the feasibility of irrigating with saline water for salt tolerant ornamental plants. This paper discusses the methodology of salt tolerance evaluation and summarizes the research results on salt tolerance of ornamental plants conducted in the past few years in our laboratory.

Methods of evaluating salt tolerance for ornamental plants

Greenhouse studies. Compared to field trials, greenhouse studies for screening salt tolerance are less labor intensive, less costly, and the environmental conditions can be more easily controlled. Salt treatments in greenhouse studies were created by adding salts to irrigation water (tap water or nutrient solution) to mimic a composition of a target saline water source or saline soil. A large number of salinity studies have used NaCl as the sole salinizing agent (Cassaniti et al., 2009; Eom et al., 2007; Marosz, 2004; Fostad and Pedersen, 2000; Wahome, 2003; Wu et al., 2001). However, composition of salts in water and salt-affected soils varies throughout the world (Carter and Grieve, 2006; Grattan and Grieve, 1999). Saline solutions with a single salt may result in misleading and erroneous interpretations about plant response to salinity (Carter and Grieve, 2006; Grattan and Grieve, 1999). In our studies, NaCl + $CaCl_2$ + $MgSO_4$ (87:8:5 by weight) have been added to tap water or nutrient solutions to mimic the major ion composition of local reclaimed waters. A wide range of salinity levels, depending on the estimated salt tolerance of the species to be tested, are prepared to distinguish the differences in plant response to increasing salinity. Even when salinity levels of irrigation water are kept the same, the maintenance of constant root zone salinity levels is difficult, and equally challenging is its measurement because of the strong influence of soil moisture content (Marosz, 2004; Tanji, 2002). The concentration of dissolved salts does not change in direct

proportion to changes in soil moisture content due to solubility, cation exchange and ion association issues.

Salinity is a dynamic property in the rootzone, due to evapo-concentration of the soil solution, water extraction, selective plant uptake from plant roots, and replenishment by irrigation or rainfall (Tanji, 2002). Salt accumulation in substrates is also influenced by plant taxa and genotypes, substrate physical-chemical properties, plant water use, irrigation frequency, and drainage and/or leaching fraction (Bernstein et al., 2006; Niu and Rodriguez, 2006a, b). To prevent salt accumulation, increasing leaching fraction and using porous, well drained substrates are effective approaches. However, high leaching fraction leads to low irrigation efficiencies (Niu et al., 2007b).

Outdoor container and field studies. Environmental conditions such as temperature, light intensity, humidity, and wind speed can considerably affect plant response to salinity (Fox et al., 2005; Niu et al., 2007a; Zollinger et al., 2007). Therefore, salt tolerance of plants from greenhouse studies provides a relative order of salt tolerance among tested plant species. The absolute salt tolerance in outdoor conditions for ornamental plants can be determined on limited number of plants with known salt tolerance under greenhouse environment. For field studies, soils will be salinized after a salt tolerance study, and thus will require replacement prior to re-utilization in subsequent experiments in the same field, unless all accumulated salts can be leached out. In our research, raised beds have been used and soils in the beds are replaced prior to each experiment (Niu et al., 2007a). Treatments were created similarly to greenhouse studies by adding salts at various ratios to irrigation water to create various salinity levels. Like greenhouse container studies, salt accumulation in the field varied among beds and locations within the same bed due to differences in water use of the plants and micro-environment. Outdoor studies using containers can provide outdoor environmental conditions, while eliminating the variation among

adjacent plots and easing the control and disposal of salinized substrates or soils. In reality, selection of method for screening salt tolerance often depends on target plant species, seasons, and availability of resources.

General responses of ornamental plants to salinity

Salt tolerance of a plant is defined as the ability to withstand the effects of high salinity without significant adverse effects such as growth or yield reduction, or foliar salt damage (Grieve et al., 2008). Salinity reduces the ability of plants to take up water, and this quickly causes reductions in growth rate, along with a suite of metabolic changes identical to those caused by water stress (Marschner, 1995; Munns, 2002). For ornamental plants, the typical symptoms of initial salt injury are stunted growth and foliar damage including leaf necrosis, and marginal leaf burn (Bernstein et al., 1972). As salt stress becomes severe, leaves are generally negatively impacted, resulting in fewer green leaves. For flowering woody shrubs and trees, buds may fail to open or grow and branches may die in salt-stressed shrubs and trees (Azza Mazher et al., 2007; Niu and Rodriguez, 2007). Salt injury symptoms are more evident under hot, dry and windy conditions than in a cool, humid environment (Fox et al., 2005; Niu et al., 2007a; Wu et al., 2001). Salt tolerance of a plant varies largely with species or even cultivar within a species (Cabrera, 2009; Niu et al., 2007a, c). The actual response of a plant to salinity is often affected by climatic conditions, type of substrate or soil, irrigation management, and plant growth stage. For each salinity level, it is possible to select a number of ornamental plants whose aesthetic values are not or only slightly affected (Bernstein et al., 1972). Obviously, as salinity levels increase, the number of plants that can tolerate the salt stress becomes smaller.

High salinity induces a series of metabolic dysfunctions in ornamental plants, including absorption of excessive minerals, nutrient imbalance, photosynthesis

inhibition, enzymatic activity, protein and nucleic metabolism and respiration (Azza Mazher et al., 2007; Marschner, 1995; Munns and Tester, 2008; Niu and Rodriguez, 2006a, b; Niu et al., 2008; Niu and Rodriguez, 2008). The extent of adverse impact of salinity on the above physiological processes depends on salinity levels and exposure period.

Growth and aesthetic responses of ornamental plants to salinity

Depending on species or genotype, growth can be quantified non-destructively by recording plant height and/or canopy size periodically. All parts of a plant, including leaves, stems, roots, and fruits may be reduced in size under saline conditions. Usually, growth reduction in shoots is greater than roots (Munns, 2002; Niu and Rodriguez, 2006a, b; Shannon et al., 1994). For agricultural crop plants, salt tolerance is often assessed based on growth or yield reduction of specific plant parts such as seeds, roots, fruits, or leaves (Maas, 1990; Pasternak and De Malach, 1994). However, for ornamental plants, aesthetic value is more important than growth rate (Bernstein et al., 1972). Therefore, visual quality, although it can be highly subjective, is an important parameter for assessing salt tolerance of ornamental plants (Devitt et al., 2005; Fox et al., 2005; Niu and Rodriguez, 2006a, b; Niu et al., 2007a; Zollinger et al., 2007). Dry matter accumulation and/or relative growth rate are commonly used to evaluate salt tolerance of plants, but this parameter is not available until plants are harvested destructively. The timing when significant differences in foliar damage symptoms appear is another parameter used for the assessment of plant salt tolerance. The earlier the salt injury is exhibited in a plant, the less is its tolerance to salinity. For a quick reference, Tables 1, 2, and 3 list relative salinity tolerances of ornamental plants evaluated based on visual salt injury and growth reduction.

Physiological responses of ornamental plants to salinity

In addition to these visible changes reflected in plant growth/size and foliar damage, plants also respond to salinity internally, expressed in changes in physiological and metabolic processes. To quantify the physiological responses to salinity, photosynthesis, leaf conductance, chlorophyll fluorescence, chlorophyll content, ion uptake and accumulation in tissues are typically measured (Cabrera, 2003; Eom et al., 2007; Niu and Rodriguez, 2006a; Quist and Williams, 1999; Wu et al., 2001; Zollinger et al., 2007; Zribi et al., 2009).

Osmotic adjustment. Osmotic adjustment occurs in plants subjected to salinity stress by accumulation of high concentrations of either inorganic ions or organic solutes (or both) (Ashraf, 2004). In our studies, we found that leaf osmotic potential of herbaceous perennials and bedding plants generally decreases with increasing salinity of irrigation water (Niu and Rodriguez, 2006a, b; Niu et al., 2010b). There were interactions between salinity and species on osmotic potentials of the tested species, indicating that the effect of salinity on osmotic adjustment varied with genotypes/species. For example, among selected bedding plants (Niu et al., 2010b), osmotic potentials of angelonia 'Purple', ornamental pepper 'Black Pearl' and 'Calico', helenium, vinca, and licorice plants decreased linearly as salinity of irrigation water increased. In angelonia 'Lavender Pink' and ornamental pepper 'Purple Flash', salinity treatment did not affect leaf osmotic potentials. In angelonia 'White' and plumbago, osmotic potential followed a quadratic fashion as salinity of irrigation water increased.

Ion uptake. Plant adaptations to salinity are of three distinct types: osmotic stress tolerance, Na or Cl exclusion, and the tolerance of tissue to accumulated Na or Cl (Munns and Tester, 2008). Salt tolerant genotypes usually have the ability to restrict Na or Cl transport to shoots. Some tolerant genotypes can tolerate high internal Na or

Cl concentrations. Ion uptake depends on species or genotype, salinity level, and the chemical composition of the soil solution (Grattan and Grieve, 1999; Niu and Rodriguez, 2008).

Niu and Rodriguez (2006a) studied differences in overall salt tolerance and Na or Cl tolerance among eight herbaceous species irrigated with saline solutions at four salinity levels. Four species died by the middle of the 12-week experiment. Among the surviving four species, the ion accumulation in shoots and roots differed. Both Na and Cl in shoots and roots generally increased with salinity of irrigation water in all species but were different among species. For example, *Gazania rigen* had the highest Na concentration in shoots (39 $mg \cdot g^{-1}$ DW) but *Delosperma cooperi* had the highest Na concentration in roots (22 $mg \cdot g^{-1}$ DW). Shoot Cl was highest in *D. cooperi* and *G. rigen*, and even in the control plants. The Cl concentration was 5 to 10 times higher in *D. cooperi* and *G. rigen* than the other two species in all treatments. Regardless of the high Na or Cl concentrations, no visual salt injury was observed in *G. rigen* and *D. cooperi*, indicating that these two species were tolerant to high internal Na or Cl concentrations. Compared to *G. rigen*, *D. cooperi* had a higher ability to exclude Na from shoots, which is an important mechanism of salt tolerance.

Salt composition affects the response of ornamental plants to salinity. Growth and ion uptake of four rose rootstocks responded to salinity and dominant salt type differently (Niu and Rodriguez, 2008). *Rosa ×fortuniana* was the most tolerant rootstock when irrigated with a saline solution dominated by sulfate, followed by *R.* 'Dr. Huey', *R. multiflora*, and *R. odorata* in descending order. However, *R. ×fortuniana* was the least tolerant rootstock when chloride was dominant in the saline solutions, *R. odorata* was the second least tolerant, and 'Dr. Huey' was the most tolerant. *Rosa ×fortuniana* and 'Dr. Huey' had a higher restriction ability of Na uptake than the other two rootstocks.

Leaf gas exchange. The most dramatic and readily measurable whole plant response to salinity is a decrease in stomatal aperture (Munns and Tester, 2008). Rates of photosynthesis per unit leaf area in salt-treated plants are often unchanged, even though stomatal conductance is reduced (James et al., 2002). Net photosynthetic rate of four rose rootstocks (*Rosa ×fortuniana, R. multiflora, R. odorata* and *R. hybrida* 'Dr. Huey'), which were irrigated with saline solutions up to 8.0 $dS \cdot m^{-1}$, were not affected (Niu, unpublished data), possibly because the healthy, young leaves were selected. The effect of salinity on photosynthesis and stomatal conductance depends on species and salinity level. For example, *Ziziphus nummularia* had greater reduction in photosynthesis and stomatal conductance than *Z. rotundifolia* (Meena et al., 2003). For the salt sensitive green ash (*Fraxinus pennsylvanica*), both stomatal conductance and net photosynthesis decreased significantly when seedlings were subjected to salt stress ranging from seawater concentration to one-tenth the concentration of seawater (Pezeshki and Chambers, 1986). Conversely, for the halophyte *Salvadora persica*, net photosynthesis, stomatal conductance and transpiration rate were not reduced by salinity stress at 200 mM NaCl compared to the control without NaCl (Maggio et al., 2000). Net photosynthesis, stomatal conductance and transpiration rates of *Phillyrea latifolia* grown at various salinity concentrations markedly decreased and the differences of these rates between the control and salinity treatments became larger over time (Tattini et al., 2002). Summarizing the above, the effect of salinity on leaf gas exchange depends on many factors such as leaf age, the level of salinity, and duration of salinity stress exposure, in addition to species and genotype.

Chlorophyll fluorescence. Chlorophyll fluorescence has been proved to be useful in salinity tolerance evaluation. The maximal photochemical efficiency of photosystem II (PSII), ratio of variable fluorescence (F_v) to maximal fluorescence (F_m), F_v/F_m, is commonly measured to examine damage in the photosynthetic

apparatus caused by salinity stress (Jimenez et al., 1997; Percival, 2005; Percival and Fraser, 2001; Sixto et al., 2006). Percival (2005) concluded that measuring chlorophyll fluorescence (F_v/F_m) of excised, salt-treated leaves under laboratory conditions can be used to evaluate salt tolerance without destroying whole plants. In our studies, we found that F_v/F_m was reduced by elevated salinities at 3.0 and 6.0 $dS \cdot m^{-1}$ in three rose rootstocks, but the reduction was small (Niu et al., 2008). The advantages of using chlorophyll fluorescence include the fact that fluorescence measurements use a light portable piece of equipment, and measurements are non-destructive and non-invasive. The effectiveness depends on species and salinity levels. For example, no differences were found in F_v/F_m in tomato leaves treated with salinity up to 200 mM NaCl (equivalent to18.3 $dS \cdot m^{-1}$) in dark-adapted leaves (Zribi et al., 2009). However, the PSII photochemistry was modified in salt-affected plants in light-adapted leaves. Naumann et al. (2008) also reported that significant differences in light-adapted fluorescence yield were observed by day 3 in *Myrica cerifera* plants treated with salinity stress while the dark-adapted fluorescence yield did not show differences between the salinity treatment and control until day 12, which was well after visible signs (day 5) of stress were apparent.

Summary

Salt tolerance of ornamental plants varies widely with species, environmental conditions, and soil or substrate. Ornamental plants, most of which are non-halophyte, have similar mechanisms of salt tolerance to agricultural crops including osmotic adjustment, Na exclusion, selective uptake of ions, and tolerance of high international accumulated Na^+ and/or Cl^-. Elevated salinity in irrigation water reduces plant size and growth, causes foliar injury (reducing aesthetic value), and increases soil salinity. A wide range of tolerance to salinity exists among tested ornamental plants.

Assessment of salt tolerance for ornamental plants should be based primary on aesthetic value.

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Table 1. Salt tolerance of bedding plants (Niu et al., 2007c; Niu et al., 2010b; Wang et al., 2010).

Botanical name	Common name	Cultivar	Tolerance
Angelonia angustifolia	Angelonia	Lavender Pink	MT
A. angustifolia	Angelonia	Purple	MT
A. angustifolia	Angelonia	White [z]	MT
Capsicum annuum	Ornamental pepper	Black Pearl	M
C. annuum	Ornamental pepper	Calico	M
C. annuum	Ornamental pepper	Purple Flash	M
Catharanthus roseus	Vinca	Rose	M
Gomphrena sp.	Gomphrena	Fireworks	MT
Helenium amarum	Helenium	Dakota Gold	MT
Helichrysum petiolatum	Licorice Plant	Silver Mist	MT
Lupinus havardii	Big bend bluebonnet		M
L. texensis	Texas bluebonnet		MT
Petunia x *hybrida*	Petunia	Baby Duck Yellow	MT
P. x *hybrida*	Petunia	Mirage Rose	MT
P. x *hybrida*	Petunia	Spreading Rose	MT
Plumbago auriculata	Plumbago	Escapade Blue	MT
Zinnia marylandica	Zinnia	Zahara Coral Rose	S
Z. marylandica	Zinnia	Zahara Fire	S
Z. marylandica	Zinnia	Zahara Rose Starlight	S
Z. marylandica	Zinnia	Zahara Scarlet	S
Z. marylandica	Zinnia	Zahara White	S
Z. marylandica	Zinnia	Zahara Yellow	S
Z. maritime	Zinnia	Solcito	S

T: tolerant; plants plants did not have any visual salt injury with minimum growth reduction at electrical conductivity of irrigation water at 12 $dS \cdot m^{-1}$ or above.

MT: moderate tolerant; plants did not have any visual salt injury with minimum growth reduction at electrical conductivity of irrigation water at 4 to 6 $dS \cdot m^{-1}$ or above.

M: moderate tolerant; plants had minimum visual salt injury and acceptable growth reduction at electrical conductivity of irrigation water at 3-4 $dS \cdot m^{-1}$.

MS: moderate sensitive; plants exhibited salt injury and growth reduction at electrical conductivity of irrigation water at 3-4 $dS \cdot m^{-1}$ or above.

S: sensitive; plants did not surve or had severe salt injury and significant growth reduction at electrical conductivity of irrigation water at 3-4 $dS \cdot m^{-1}$ or above.

Table 2. Relative salt tolerance of herbaceous perennials and groundcovers (Niu and Rodriguez, 2006a, b; Niu et al., 2007a, b).

Botanical name	Common name	Tolerance
Achillea millefolium	Yarrow	M
Agastache cana	Wild hyssop	MS
Berlandiera lyrata	Chocolate daisy	S
Ceratostigma plumbaginoides	Hardy blue plumbago	M
Delosperma cooperi	Ice plant	T
Echinacea purpurea	Purple coneflower	S
Gaillardia aristata	Firewheel	MT
Gazania rigen	Gazania	MT
Lantana	New gold lantana	MT
L. camara	Purple lantana	M
Lavandula angustifolia	Lavender	MS
Lonicera haliana	Honeysuckle	MT
Penstemon eatonii	Firecracker penstemon	S
P. pseudospectabilis	Pink showy penstemon	S
P. strictus	Rocky mountain penstemon	S
Rosmarinus officinalis	Rosemary	MT
Rudbeckia hirta	Black-eyed susan	S
Salvia coccinea	Scarlet sage	S
Teucrium chamaedrys	Germender	M
Verbena canadensis	Purple verbena	M
V. hybrida	Garden verbena	M
V. macdougalii	Spike verbena	M

For tolerance symbols: T, MT, M, MS, S, refer to the footnote of Table 1.

Table 3. Relative salt tolerance of ornamental shrubs and trees (Niu and Rodriguez, 2007; Niu et al., 2010a).

Botanical name	Common name	Tolerance
Cercis canadensis var. Mexicana	Mexican redbud	S
Chilopsis linearis	Desert willow	MS
Elaeagnus angustifolia	Russian olive	MS
Fraxinus pennsylvanica	Green ash	MS
Prunus angustifolia	Sand plum	S
P. besseyi	Sand cherry	S
P. serotina	black cherry	S
Sophora secundiflora	Texas Mountain laurel	M
Ulmus parvifolia	Chinese elm	MT

For tolerance symbols: T, MT, M, MS, S, refer to the footnote of Table 1.